United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-RP-434
September 1990

Damage by the Sitka Spruce Weevil *(Pissodes strobi)* and Growth Patterns for 10 Spruce Species and Hybrids Over 26 Years in the Pacific Northwest

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Abstract

Mitchell, Russel G.; Wright, Kenneth H.; Johnson, Norman E. 1990. Damage by the Sitka spruce weevil *(Pissodes strobi)* and growth patterns for 10 spruce species and hybrids over 26 years in the Pacific Northwest. Res. Pap. PNW-RP-434. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Ten species and hybrids of spruce (*Picea* spp.) were planted and observed annually for 26 years at three coastal locations in Oregon and Washington to evaluate growth rates and susceptibility to the Sitka spruce weevil (= white pine weevil), *Pissodes strobi*. The 10 spruce were: Sitka spruce, Norway spruce, Lutz spruce, black spruce, white spruce, Engelmann spruce, Yeddo spruce, Sakhalin spruce, an Engelmann × white spruce cross, and a Sitka × white × white backcross. Results showed Sitka and Norway spruce grew well but were badly damaged by severe weevil attack. Infestation levels peaked at about 30 percent between 9 and 15 years and dropped to about 8 percent at the end of the study. Lutz spruce—a natural Sitka/white spruce hybrid—was rarely weeviled and some trees grew well while others grew poorly. The conclusion was that Lutz spruce demonstrates resistance to weevil attack, that the resistance is genetically based, and that this resistance could be exploited in a tree-improvement program. The other species and hybrids had very little weevil damage, but survival and growth were poor.

Keywords: Spruce species, white pine weevil, host resistance.

Contents

Introduction

Sitka spruce, *Picea sitchensis* (Bong.) Carr., is a very fine tree. It grows fast and yields high-quality wood with several commercial uses. As a coastal tree, it fills some important ecological niches right to the ocean edge and along estuaries and riparian zones leading inland from the sea. It is also tolerant of brush competition and resistant to browsing by deer and elk (Fowells 1965, Harris 1984, Ruth and Harris 1979).

Although seemingly a tree for everyone, Sitka spruce has long been out of favor in forest management (Wright and Baisinger 1955). Foresters in the Pacific Northwest rarely plant it anymore or even do much to encourage it. The problem stems from the white pine weevil, *Pissodes strobi* (Peck), a reproduction pest that attacks spruce terminals and affects height growth and stem form (Silver 1968). Best known on the west coast by its older name—the Sitka spruce weevil—the insect is a chronic problem in most young, inland stands in British Columbia, Washington, Oregon, and northern California (Wright 1960). It is a lesser pest in the cool fog-zone close to the coast and is completely unknown in Alaska and the Queen Charlotte Islands (McMullen 1976).

Adult weevils can live as long as 4 years (McMullen and Condrashoff 1973). They overwinter as adults on the forest floor and within the foliage of the crown, usually on or near the brood tree. In the spring, just as the new terminals begin to expand, the adults locate new trees and insert several eggs in the bark at the top of last year's terminal (Gara and others 1971, Johnson 1965, Overhulser and Gara 1975). Larvae from those eggs mine downward in the cortical area of the terminal and gradually sever the water-conducting tissue to the elongating, new terminal. The old terminal dies, and the new terminal turns yellow and starts to droop when it is about half grown. Meanwhile, one or more laterals turn upward to form new terminals (fig.1). Impact on the tree is thus reflected in reduced height growth (affecting both volume potential and the ability of the tree to compete with its neighbors) and poor form because of multiple stems and crooks in the main stems (Alfaro 1989, Carlson 1966).

Several studies were undertaken over the years to find a solution to the weevil problem. One program involved the planting of several exotic and hybrid spruce trees to compare their growth potential and weevil susceptibility with that of native Sitka spruce. Another objective was to identify long-term infestation patterns. This paper summarizes 26 years of observations and measurements on those plantations and replaces an earlier, 15-year progress report (Mitchell and others 1974).

Methods and Procedures

The study began in 1958 with seedling plantations of 10 spruce species and hybrids on each of three plots near the coastal town of Raymond, Washington. One plot (Brooklyn) was in a swampy site about 30 miles from the ocean; another (Raymond) was about 15 miles from the ocean on a gentle, northwest-facing slope overlooking the town of Raymond. The third plot, by a stream a few miles northeast of Raymond, was eventually abandoned because of severe damage by beavers. In 1961, a fourth plot (Cascade Head), identical to the others, was established in Oregon about 3 miles from the ocean on a moderately steep, northeast-facing slope in the Cascade Head Experimental Forest near Lincoln City. All study trees were grown in nurseries for 2 to 3 years and randomly outplanted on the plots at a spacing of 10 feet. Some extra trees were planted as reserves just off the plots to replace trees that might die during the study. In-growth of native trees and shrubs were periodically rogued to reduce competition; nevertheless, the 10-foot spacing was too close, and competition near the end of the study became severe among many of the plot trees and reserves.

Figure 1—Damage to Sitka spruce by *Pissodes strobi.* **A.** Weevil larvae mine down the terminal shortly after bud burst and, in midsummer, form pupal cells under the bark at the end of the mines. **B.** New growth arising from attacked terminal dies and starts to droop when the mining larvae grow large enough to sever conductive tissue. **C.** Multiple tops often develop when laterals below the killed terminal assume dominance. **D.** Killed terminals overgrown by laterals-turned-to-leaders result in poor stem form and decreased wood quality.

Trees and their origins were as follows:

Picea sitchensis (Sitka spruce)—Olympic Peninsula, Washington
P. abies (L.) Karst. (Norway spruce)—Harz Mountains, Germany
P. × *lutzii* Little (Lutz spruce)—seed routed through Tornby, Denmark, from unknown source, but believed to be British Columbia
P. mariana (Mill.) B.S.P. (black spruce)—northern Minnesota
P. glauca (Moench) Voss (white spruce)—northern Michigan
P. engelmannii Parry ex Engelm. (Engelmann spruce)—western Montana
P. jezoensis (Sieb. & Zucc.) Carr. (Yeddo spruce) and *P. glehnii* (Fr. Schmidt) Masters (Sakhalin spruce)—central Japan
P. sitchensis × *glauca* × *glauca* and *P. engelmannii* × *glauca*—both open-pollinated crosses at Horsholm, Denmark, from unknown origins.

Except for 4 years when the Cascade Head plot was not examined (1964-67), plot trees and reserves were evaluated annually for weeviling and for height growth of trees. Diameter at breast height (d.b.h.) was measured periodically. Data presented in this paper were collected through 1983 for the Washington plots and 1986 for the Oregon plot.

The relation between degree of weevil infestation and plantation age (fig. 2) was developed using smoothing procedures described by Tukey (1977). Data smoothing is an exploratory statistical procedure that summarizes data by describing the central trend and reducing variation. No assumptions are made about model form, and no mathematical prediction model is developed. This approach was selected because the temporal length of the data set was too short to be sure of a model form.

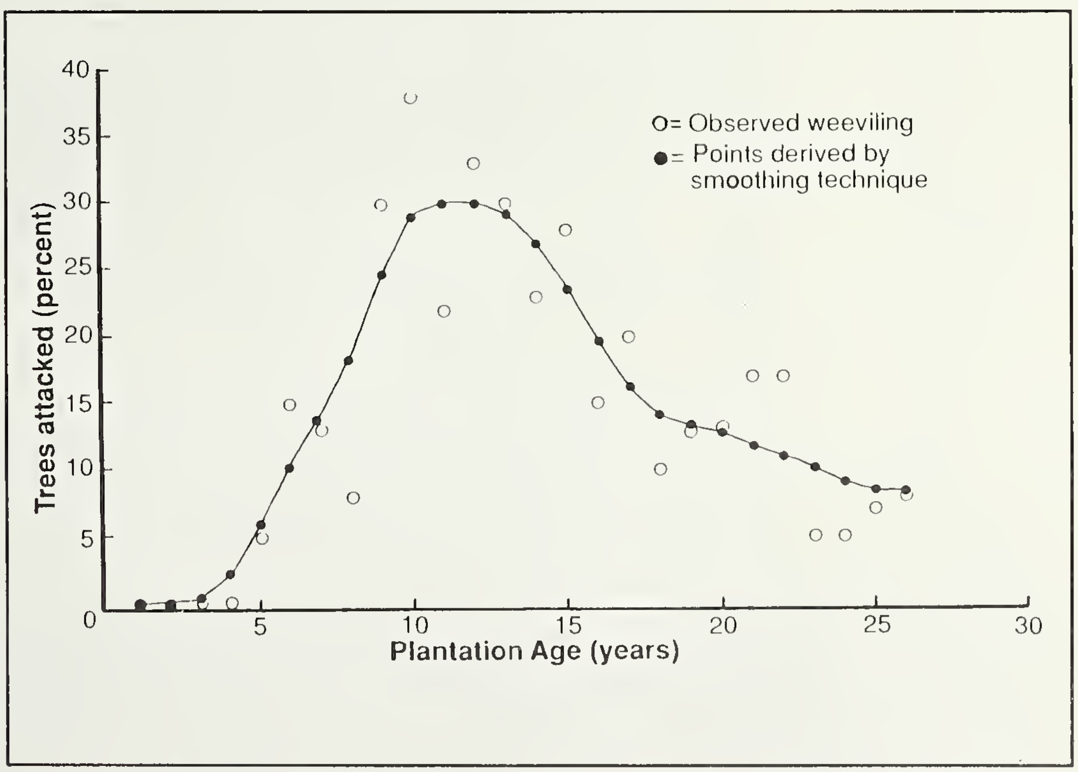

Figure 2—Pattern of weeviling in Sitka and Norway spruce over 26 years (sum of three plots). Smoothing technique (Tukey 1977) shows central trend.

Results
Weeviling

- The two best-growing spruce, Sitka and Norway, were also the most susceptible to the weevil (table 1). They were weeviled a total of 223 times—134 for Sitka and 89 for Norway[1].

- Lutz spruce, the natural Sitka spruce-white spruce hybrid found in Alaska and northern British Columbia (Little 1953, Wright 1955), grew almost as fast as Sitka and Norway spruce, but was weeviled only nine times. Two trees were weeviled twice and five were weeviled once. Several aborted attacks were recorded when the trees were small and egg niches were easy to see. In terms of exposure (tree-years), Lutz, Sitka, and Norway spruce all had equal opportunities for attack.

- Six attacks were recorded for white spruce, black spruce, and Engelmann spruce, which shows they can be attacked but says little about their intrinsic resistance to attack. All three species grew rather slowly, and trees with short terminals were rarely weeviled.

- The Sitka × white × white backcross grew slightly better than the white, black, and Engelmann spruce, and was attacked. All attacks, however, were aborted.

- Sitka and Norway spruce were most susceptible (on all three plots) when the plantations were 9 to 15 years old; some 30 percent of the trees were attacked at the peak period (fig. 2).

- Weeviling declined sharply after the plantations were 21 years old; beyond those years, the total number of weeviled trees was four for Raymond, one for Brooklyn, and six for Cascade Head.

- Sitka spruce was attacked most often on the Raymond plot, where growth was best, and least often on the swampy Brooklyn plot, where growth was poorest; Norway spruce was weeviled about equally on all three plots (table1).

- Only three Sitka spruce escaped weeviling—a poor-growing tree and a fast-growing tree at Brooklyn and a fast-growing tree at Cascade Head. Three slow-growing Norway spruce also escaped the weevil—one on each plot.

- Most Sitka and Norway spruce were weeviled several times throughout the study, in the range of 4 to 6 times per tree. Maximum number of attacks per tree was 9 for Sitka spruce and 10 for Norway spruce.

- When terminals were killed, one or more laterals assumed dominance and became the new leader(s). When only one lateral became dominant after weeviling (as often happened with Sitka spruce), consecutive years of weevil attacks on individual trees were rare—new tops usually grow too slowly to be susceptible the 1st year (and often the 2d year) after they become terminals.

- Because several laterals often became dominant after weeviling, many trees had several tops, so these trees could have multiple weeviling in the same year and repeated weeviling in consecutive years. Both phenomena were commonly observed in this study.

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[1] Weevil attacks on more than one leader of a single tree in the same year were counted as a single attack.

Table 1—Growth and weevil history of 10 spruce species or hybrids on 3 plots in Oregon and Washington

Species or hybrid	Surviving trees		Mean height of trees	Mean d.b.h. of trees	Trees weeviled
	Number		*Feet*	*Inches*	*Number*
	RAYMOND PLOT				
Sitka	10		43.1	13.2	61
Norway	10		43.2	10.6	33
Lutz	10		39.0	7.0	4
Sitka × white × white	3		31.6	3.7	0
Black	8		26.5	3.8	0
Engelmann	7		24.6	2.9	0
White	7		22.3	3.7	0
Engelmann × white	3		20.4	2.7	0
Yeddow	3		12.7	1.5	0
Sakhalin			Last tree died in 1983.		
	BROOKLYN PLOT				
Sitka	10		33.7	6.5	26
Norway	10		34.7	5.7	30
Lutz	10		29.2	3.8	1
Sitka × white × white	4		24.4	3.8	0
Black	9		27.8	3.8	2
Engelmann	6		22.3	2.4	1
White	5		21.4	2.7	0
Engelmann × white			Last tree died in 1982.		
Yeddow	3		7.9	0.3	0
Sakhalin	1		2.2	—	0
	CASCADE HEAD PLOT				
Sitka	10		42.9	12.6	47
Norway	10		39.6	8.0	26
Lutz	10		44.0	9.8	4
Sitka × white × white	7		24.7	3.8	0
Black	9		21.4	2.9	1
Engelmann	4		27.3	4.1	0
White	2		25.0	4.0	2
Engelmann × white	2		16.7	2.1	0
Yeddow	5		9.3	1.0	0
	ALL PLOTS				
Sitka	30	(100)[1]	39.9	10.7	134
Norway	30	(100)	39.2	8.1	89
Lutz	30	(100)	37.4	6.9	9
Sitka × white × white	14	(47)	27.6	3.8	0
Black	26	(87)	25.2	3.5	3
Engelmann	17	(57)	24.4	3.0	1
White	14	(47)	22.4	3.4	2
Engelmann × white	5	(17)	18.9	2.5	0
Yeddow	11	(37)	9.8	0.9	0
Sakhalin	1	(5)	2.2	—	0

[1] Percent survival.

- One Norway spruce was attacked 9 years in a row and another 4 years in a row. Four different Sitka spruce were attacked 3 years in a row.

- One Norway spruce with multiple leaders had four terminals weeviled in a single year. Two terminals weeviled in the same year were fairly common for both Norway and Sitka spruce.

Growth

- Height growth of the three best plot trees (Sitka, Norway, and Lutz spruce) was about the same as adjacent, native Sitka spruce but noticeably less than adjacent western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco.

- Within plots, Sitka and Norway spruce grew the best of any of the spruce species and hybrids, in both height and diameter. Because of severe weeviling, however, most trees had multiple stems and severe crooks in each stem (fig. 3). The best Sitka spruce was at Cascade Head and was never weeviled; in 26 years, it grew 59 feet tall and to 16.1 inches d.b.h. The best Norway spruce was on the Raymond plot and was weeviled twice; in 26 years, it grew 57 feet tall and to 13.9 inches d.b.h.

- Lutz spruce was the third-best plot tree for average height and diameter growth, and (because it was weeviled so seldom) it had the best form of all the trees on all three plots. The striking characteristic of its growth pattern was the variation—some trees grew poorly but others grew better than the best Sitka and Norway spruce (fig. 4). A Lutz spruce at Cascade Head was the largest of any plot tree; 26 years after planting, it was 67 feet tall and 16.8 inches d.b.h. It was weeviled once.

Figure 3—Norway spruce 19 from Raymond, Washington, plot. It was weeviled 4 of the 7 years between 1967 and 1973 and once again in 1980. Some limbs were removed to show forking and multiple stems.

Figure 4—K.H. Wright and Lutz spruce 22 on the plot at Raymond, Washington. In the 25-year span reflected in these photographs, Lutz spruce grew from 4 to 60 feet in height and to 13.5 inches d.b.h. Height and d.b.h. of K.H. Wright appear unchanged.

- The next best tree for growth was the Sitka × white × white backcross, but survival was poor.

- Engelmann, white, and black spruce, and the Engelmann × white hybrid all grew poorly and, except for black spruce, had poor survival. The black spruce might make a good ornamental in coastal areas—it was unaffected by gall aphids (subfamily *Adelginae*) and had attractive, blue foliage.

- The two spruce species from Japan, Yeddo and Sakhalin spruce, were clearly unsuited for the coastal environment in Oregon and Washington. None of the trees would have survived for more than 1 or 2 years if they had not been protected from competition.

Weeviling and Growth

- Correlating number of weevil attacks with mean tree diameters (table l) suggested the same linear relationship observed by Gara and others (1971), McMullen and others (1987), and Silver (1968); that is, the probability of weevil attack is directly related to the rate of tree growth. The r^2 was 0.84 for all plots, 0.89 for Raymond, 0.79 for Brooklyn, and 0.65 for Cascade Head.

- The conspicuous outlier was Lutz spruce; as shown in table 2, recorded attacks on Lutz spruce were far less than would be expected for a tree growing that fast (9 recorded attacks vs. 56 predicted).

- Note, however, that the correlation is based on mean diameters and accumulated attacks on several trees, obscuring anomalies associated with individual trees, such as the way a tree recovers from a weevil attack. When the focus is on individual tree-chronologies (tree diameter at the end of 26 years vs. the total number of weevilings for that particular tree), the correlation becomes rather faint. The best r^2 was 0.33 for Sitka spruce and the worst was 0.06 for Norway spruce. Lutz spruce had an r^2 of 0.13. Attacks were too few to test the other species and hybrids.

Table 2—Relation between mean d.b.h. of 8 spruce hosts and observed and predicted weevil attacks over a 26-year period

Spruce hosts	Mean d.b.h.	Weevil attacks in last 26 years	
		Observed	Predicted[1]
	Inches	*Number*	*Number*
Sitka	10.7	134	117
Norway	8.1	89	76
Lutz	6.9	9	56
Sitka × white × white	3.8	0	7
Black	3.5	3	2
White	3.4	2	0
Engelmann	3.0	1	–6
Engelmann × white	2.5	0	–14

[1] Prediction equation: $Y = -54 + 16X$; $R^2 = 0.84$.

Discussion

Lutz spruce may be a valid candidate to replace Sitka spruce in coastal areas of Oregon and Washington. The tree seems quite resistant to weeviling and some trees have growth equal to—and sometimes superior to—native Sitka spruce. The resistance seems to have a genetic foundation. Based on growth, the rate of attack on Lutz spruce ought to be six times greater than observed.

The seed source of the Lutz spruce is unknown, but we can speculate that the seed was randomly collected from a hybrid swarm characterized mostly by F_1 crosses. The hypothesis is based partly on the observation that a few Lutz spruce were large and looked like Sitka spruce, a few were small and looked like white spruce, but most were intermediate in size and had characteristics of both Sitka and white spruce. Also, height and diameter are known to be inherited as quantitative traits in trees (Zobel and Talbert 1984). Accordingly, if (on the average) the trees were F_1 crosses, height and diameter growth of the Lutz spruce should be half the summed growth of the Sitka and white spruce growing on the same sites.

The intermediacy of Lutz spruce as a hybrid between Sitka and white spruce is supported by the study data. If we assume an average height of 54 feet for unweeviled Sitka spruce—using observed height and correcting for weevil impact (Carlson 1966) —and a 22-foot observed height for white spruce, the intermediate height of 38 feet ((54 + 22)/2) is rather close to the 37-foot average height observed for Lutz spruce. The same model for diameter projects an intermediate diameter of 7 inches d.b.h. ((11 + 3)/2), which compares to an observed d.b.h. of 6.9 inches for Lutz spruce.

Any normal hybrid swarm ought to have some backcrosses dominated by Sitka spruce genes and some dominated by white spruce genes. The few weevilings of Lutz spruce in this 26-year study (7 trees with 9 attacks) suggest that the weeviled trees may have been backcrosses dominated by Sitka spruce genes. From the standpoint of forest management, a backcross to Sitka spruce (Sitka × white × Sitka) would be a tradeoff—offspring would have improved height and diameter growth, but susceptibility to the weevil would likely be reintroduced into the tree population.

Norway spruce grew rather well on all three plots and, were it not for the weevil, could replace Sitka spruce with only some reduction in volume. With the weevil, though, use of the tree species would seem to be risky. When Norway spruce is weeviled, several lateral branches typically compete for dominance. As a result, a tree that has been weeviled three times may have as many as nine tops and a crown that occupies enough space for several trees (fig. 3).

Weevil damage has been suspected of being most severe when a stand is young and gradually declining as the stand ages (McMullen and others 1987). Data from this study support that thesis, suggesting that the incidence of weeviling peaks at 30 to 40 percent between the ages of 9 and 15 and then, at about age 25, declines to some asymtotic level less than 10 percent (fig. 2).

The decline in weevil damage may be related to stand environment. In this study, rate of height growth, which affects weeviling, did not change significantly from the years of peak weeviling, and no changes in weather patterns were detectible. Also, the same pattern was observed on both Norway and Sitka spruce. Possibly, weevil oviposition and winter hibernation are affected as the terminals grow higher and crown closure changes the environment in the lower canopy. Also, older trees may not produce as many weevils as the younger ones. Overhulser and others (1972) observed that attacks are greatest on trees attacked the first time, and brood survival declines on trees previously infested. Still another explanation is that the weevil population declined as the spruce food supply in the area was being eliminated by competition with other tree species. Alfaro (1982) noted that weeviling declined in a mixed-species plantation in a pattern similar to the one in this study; at the same time, weeviling continued high in an adjacent, pure spruce plantation.

Conclusions

On a purely technical basis, the results of this investigation suggest that research aimed at developing weevil resistance through a program of controlled crossing has merit. If our hypothesis is correct, an F_1 Sitka spruce x white spruce cross would produce a hybrid that is 100 percent resistant to weevil attack but also a tree that would not grow quite as fast as Sitka spruce. A backcross to Sitka spruce would improve growth about 25 percent but reintroduce weevil susceptibility into the tree population (about 50 percent of the progeny would be susceptible if resistance is controlled by a dominant, single gene). But, coupled with a deliberate decision to overplant, 50 percent resistance might be acceptable as a management strategy; weevils attack spruce when they are rather young, and a precommercial thinning at age 15 would likely remove most of the susceptible trees.

Programs to develop controlled crosses, though, tend to be expensive and long term, and they become even more burdensome when coupled with expensive operations like overplanting and precommercial thinning. An alternative approach, but with less genetic gain, would be to collect seed from stands showing predominantly Sitka characteristics but some evidence of white spruce introgression. Two such stands have been identified in the literature: Daubenmire (1967), using morphological characteristics, identified one near the mouth of the Skeena River in British Columbia; Copes and Beckwith (1977), using electrophoresis techniques, identified another near Seward, Alaska. Other stands likely exist and could be identified with some searching. The aim of collecting in such

stands would be to improve the chances of getting seed from Sitka × white × Sitka backcrosses. The advantage of this approach would be that seedlings could be available for outplanting in a relatively short time and that the gene pool would be rather wide. The disadvantage would be the uncertainty—growth may be less than hoped for and, depending on the amount of introgression by white spruce and the number of genes involved in resistance, a large percentage of the population may be susceptible to attack by the weevil. The use of tree populations from greatly different latitudes is also part of the problem because of the unpredictable influence of photoperiod effects on adaptation and growth behavior.

Another solution, one that would also be fast and offer less uncertainty, would be to take advantage of clonal technology and use trees already proven to be weevil resistant. Rooting young spruce is rather easy (Copes 1987, Roulund 1971), and vegetative propagation offers the opportunity of genetic improvement and large production from a small base. About 10 Lutz spruce on our plots grew well to moderately well and suffered little or no weeviling. Also, two Sitka spruce grew well and were unweeviled. Although this approach can be labor intensive (Gill 1983), new cloning techniques are reducing costs. A disadvantage of cloning, in this instance, is that it would offer very little genetic diversity. Another problem is that cuttings from trees more than 5 or 6 years old (from the seed) present problems of plagiotrophy, poor survival, and poor vigor (Baldwin and Mason 1986).

Lastly, western hemlock and Douglas-fir will grow almost anywhere Sitka spruce will grow, and often better. Perhaps it would be better to stay with local Sitka spruce populations and deal with the weevil directly. Outside of the fog zone close to the coast, there are only a few places, mostly in riparian environments, where spruce is the best planting choice among the local tree species. In these places, where plantations would be small and isolated from other spruce, the weevil problem would have a short, identifiable life span (fig. 2), and a control program dealing directly with the weevil might be feasible. Use of broadcast insecticides is unlikely in a riparian environment but, because of the small areas involved and the short life of the program, some exotic or labor-intensive programs might prove practical. Clipping infested terminals, growing the trees under a nurse cover of red alder (*Alnus rubra* Bong.) (McLean 1989), spraying terminals individually (Johnson and Zingg 1968, Warkentin and others 1984), stem injections with systemics, or mating confusion using sex pheromones merit consideration.

Acknowledgments

Many people, in the long course of this study, assisted with plot installation, plot maintenance, and data collection, often in extremely miserable weather: Darrel Barstow, Paul Buffam, Larry Carpenter, Don Curtiss, Gary Daterman, Mark DeBose, Jack Duffield, Mike Fenning, Jack Heikkenen, Jim McCoy, Alan Mitchell, Keith Mitchell, Paul Mitchell, Gene Paul, Roger Ryan, Bob Ruth, Roy Silen, Milt Stelzer, Walt Swenson, Joe Wheat, Ron Wiggins, Boyd Wilson, Jack Winjum, and Vern Yerkes. We thank them all for their contributions.

We also thank several people for reviews, information, and helpful suggestions at various stages in manuscript preparation: Don Copes, Bob Gara, Tim Max, Dave Overhulser, Bent Soegaard, and Martha Brookes. We are especially grateful for the detailed comments and excellent suggestions of Sharon Friedman and Roy Silen. Some color photographs were provided by the Oregon Department of Forestry.

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Ten species and hybrids of spruce (*Picea* spp.) were planted and observed annually for 26 years at three coastal locations in Oregon and Washington to evaluate growth rates and susceptibility to the Sitka spruce weevil (= white pine weevil), *Pissodes strobi*. The 10 spruce were: Sitka spruce, Norway spruce, Lutz spruce, black spruce, white spruce, Engelmann spruce, Yeddo spruce, Sakhalin spruce, an Engelmann × white spruce cross, and a Sitka × white × white backcross. Results showed Sitka and Norway spruce grew well but were badly damaged by severe weevil attack. Infestation levels peaked at about 30 percent between 9 and 15 years and dropped to about 8 percent at the end of the study. Lutz spruce—a natural Sitka/white spruce hybrid—was rarely weeviled and some trees grew well while others grew poorly. The conclusion was that Lutz spruce demonstrates resistance to weevil attack, that the resistance is genetically based, and that this resistance could be exploited in a tree-improvement program. The other species and hybrids had very little weevil damage, but survival and growth were poor.

Keywords: Spruce species, white pine weevil, host resistance.

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